Development of 16μm×16μm Digital Micromirror Array Suitable for Seamless-picture Projection Display System

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Abstract

We have developed 16μm×16μm digital micromirror array suitable for seamless-picture projection display system. This structure can improve the picture quality by making seamless-picture image when combined with high-fill-factor microlens array to focus lights onto the mirror center. The fabricated micromirror shows excellent dynamic performances including the resonant frequency of 400 kHz.

1. Introduction

For several years, light valve devices based on Micro Electro Mechanical Systems (MEMS) technology, especially micromirrors, have received much attention and have gained large market share in the microdisplay areas such as projection TVs, projectors, and cinemas [1]-[3]. However, as new microdisplay markets of portable displays are emerging and the performances of other displays such as LCD, GLV, and LCOS are rapidly improved [4]-[6], it has been strongly required to improve the micromirror performances such as fill-factor, pixel resolution, switching time, and reliability [7], [8].

From this perspective, in this paper, we have proposed a seamless-picture projection display system integrated with micromirror and microlens arrays, and also developed 16μm×16μm digital micromirror array suitable for the proposed system. Fig.1 shows the schematic view of the proposed seamless-picture projection display system composed of the micromirror array and two sheets of high-fill-factor microlens array. Using two sheets of the microlens array, the collimated incident light is focused onto the center of the individual micromirrors, reflected without any loss in the mirror edges and gaps, then come out of the system as a collimated light again. In this way, we can achieve a seamless picture so as to improve the picture quality remarkably. In order to realize the proposed system, we need high-fill-factor microlens array, for which lots of work are already in progress [9], [10] and the micromirrors having no center hole in the mirror plate.

Therefore, in this paper, we have focused to develop high-performance 16μm×16μm digital micromirror array utilizing interdigitated cantilevers as a spring so that the topmost mirror plate has no center hole.

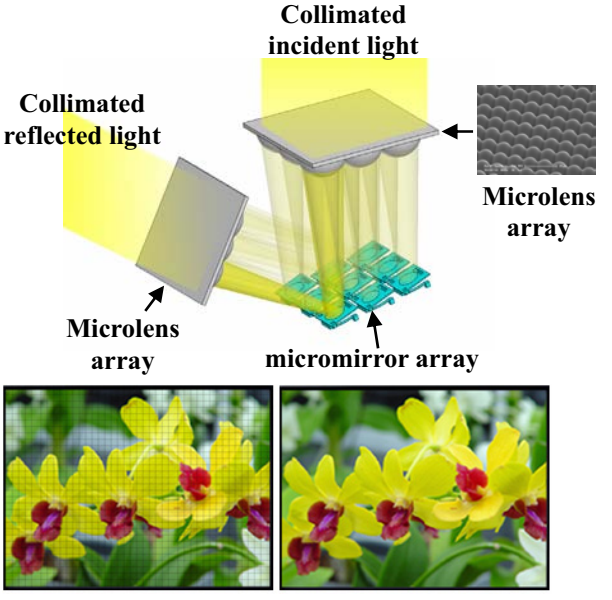

Fig. 1. Schematic views of the proposed seamless-picture projection display system composed of the micromirror array and two sheets of high-fill-factor microlens array, and the picture quality improvement expected (left to right).

2. Structure Design and Operation Principle

Fig. 2 shows the schematic view of the micromirror structure explicitly showing the unique interdigitated cantilevers and the mirror plate with no center hole.

The micromirror consists of three layers of three address electrodes, three cantilevers, and the mirror plate, respectively. Note that the cantilevers are placed in parallel but actuated toward the opposite direction with each other, so called interdigitatedly.

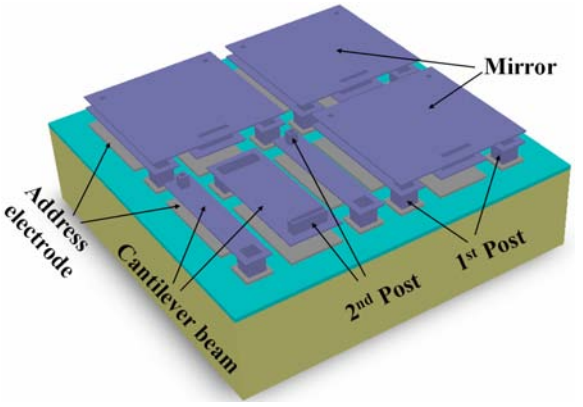

Fig. 2. A schematic view of the 2×2 micromirror array using interdigitated cantilevers

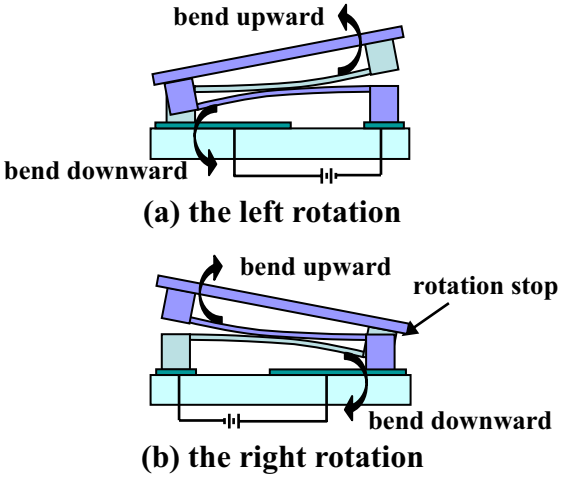

Fig. 3. Symmetrical operation principles of the micromirror using interdigitated cantilevers.

Fig. 3 shows the operation principle of the micromirror. The micromirror using interdigitated cantilevers can behave a symmetric rotation in two opposite directions through a bending actuation of cantilevers. When a driving voltage is applied in the center address electrode, the center cantilever spring is bent down, whereas the remaining outer two cantilever springs are bent up. In this way, the micromirror rotates in one direction. When a driving voltage is applied to the outer two electrodes, the mirror rotates in the opposite direction by means of the opposite reaction of the cantilevers. During symmetrical rotations of the mirror, there is no electrical shortage if we design the height of the 2nd post smaller than that of the 1st post.

3. Fabrication

In this fabrication of micromirror with interdigitated cantilevers, we have used polyimide as sacrificial layer and aluminum as the material of structure to improve the thermal stability and reduce the size of mirrors differently from our previous works [10], [11].

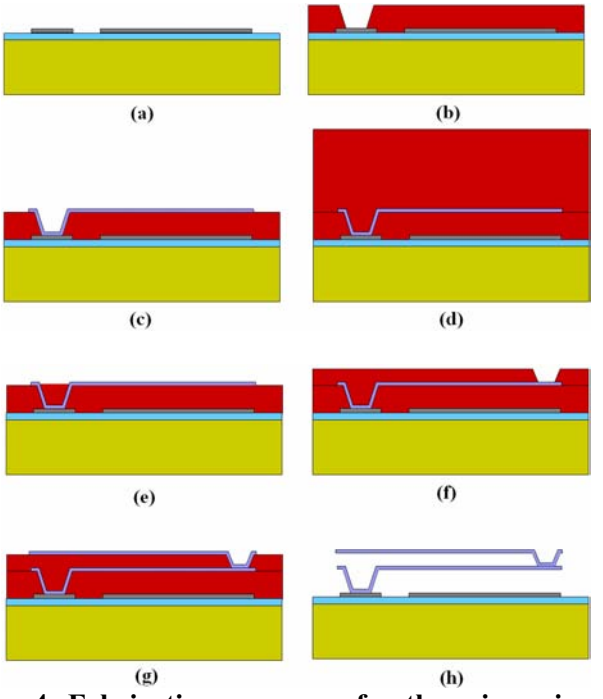

Fig. 4. Fabrication processes for the micromirror with interdigitated cantilevers: (a) bottom electrode patterning, (b) polyimide deposition and 1st post patterning, (c) cantilever patterning, (d) trench filling by polyimide, (e) etch back by plasma, (f) polyimide deposition and 2nd post patterning, (g) mirror patterning, and (h) dry release by O_2 plasma

The fabrication process is shown in fig. 4. Firstly, the aluminum layer with 3000Å thickness is sputtered and patterned for the bottom electrodes. Then, the 1st sacrificial layer of polyimide, PI-2555, manufactured by DuPont, is spin-coated to have a film thickness of about 2μm after curing. The cured polyimide is patterned by RIE using the plasma mixed in ratio of 90% O_2 and 10% CF_4 with a photoresist mask of 6um in thickness for 1st post as shown in fig. 4(b). Fig. 4(c) shows the process for the interdigitated cantilever

formation that 2000Å aluminum layer is sputtered and patterned by wet etch using an aluminum etchant.

We use the trench filling and etch-back process to planarize the 1st sacrificial layer as shown in fig. 4(d), (e). Trenches with 2μm in depth in the 1st sacrificial layer are successfully filled by spin-coating of the thick-enough polyimide and proper etch-back to the aluminum layer using RIE with the plasma of 80% O_2 and 20% CF_4. The processes for 2nd posts and the mirror are the same with those for the 1st posts and cantilevers except for the 2nd sacrificial layer thickness of 1μm. After the topmost aluminum layer is sputtered and patterned by the aluminum etchant for a mirror plate, the micromirror is dry released by O_2 plasma as shown in fig. 4(g), (h).

4. Results and Discussion

Fabrication results

Fig. 5 shows scanning electron microscopy (SEM) images of the fabricated micromirror array with over 10×10 micromirrors. These micromirrors are made of 1st posts with 2μm thickness, cantilevers with 0.2μm thickness, 2nd posts with 1 μm thickness, and mirror with 0.2μm thickness. All of the fabricated micromirrors have flat interdigitated cantilever beams and planar mirror plates without any stress. Especially, we have obtained the planar mirror plate without topography of 1st posts through trench filling and etch back processes. Three holes remained on the mirror surface are originated from the 2nd posts.

Measurement results

Fig. 6 shows the deflection angles of the 16μm×16μm micromirror as a function of applied voltages, which are measured by an optical surface profiler. The measured maximum deflection angle was ±8.9˚ at the applied voltage of 85V. The rotation angle is not increased more than 8.9˚ at a voltage above 85V because the 1st post played as a rotation stop (as can be seen in Fig. 3).

Fig. 7 shows the resonant frequency response of the 16μm×16μm micromirror, which is measured by Polytec Laser Doppler Vibrometer (LDV). The measured resonant frequency of the micromirror was about 400 kHz. We have gained such a high resonant frequency of 400 kHz since we used unique spring structure of three interdigitated cantilevers different from one common twisting hinge and the whole structure is simple and light. We need to investigate later all the meaningful comparison between the interdigitated cantilevers and the common twisting hinge.

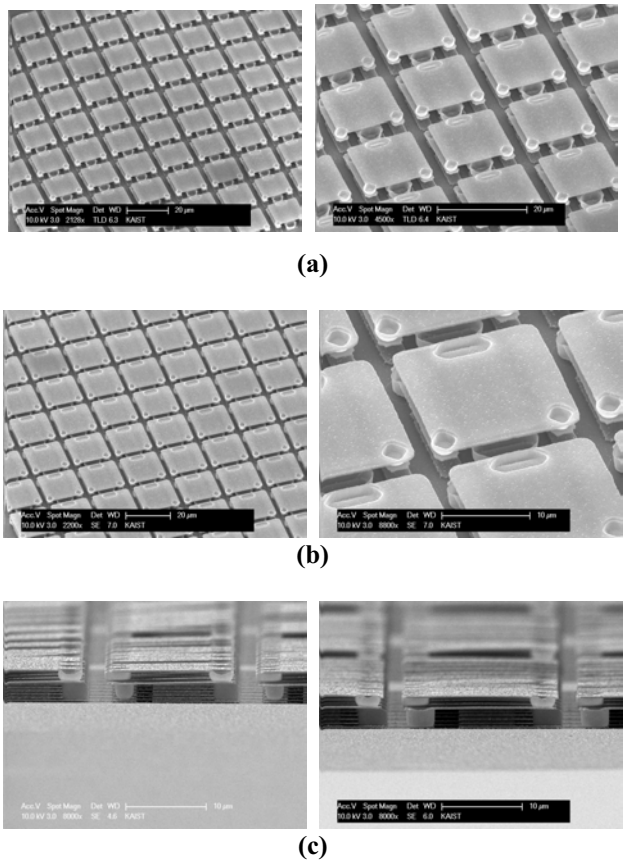

Fig. 5. SEM images of the fabricated micromirror array: (a) top view of the 16μm×16μm micromirror array, (b) top view of the 18μm×18μm micromirror array, (c) bird's-eye view of the 16μm×16μm (left) and 18μm×18μm (right) mirrors

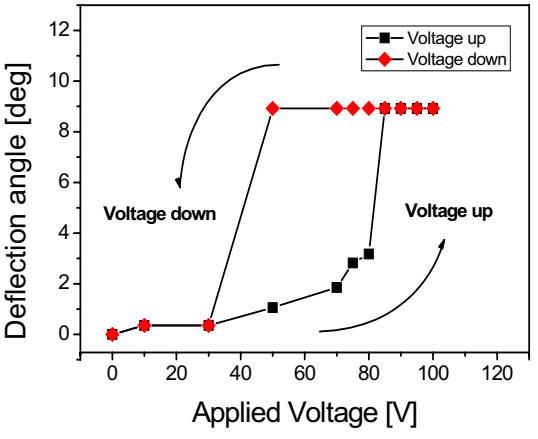

Fig. 6. Deflection angles of micromirror with 16μm×16μm size as a function of applied voltage

Switching time responses of the fabricated 16μm×16μm micromirror by applying step voltages of 25V in the frequency of 2 kHz is measured using LDV, as shown in Fig. 8. When the response time is defined as the time taken from 10% to 90% of maximum displacement, that of the fabricated 16μm×16μm micromirror was measured as about 15 μs.

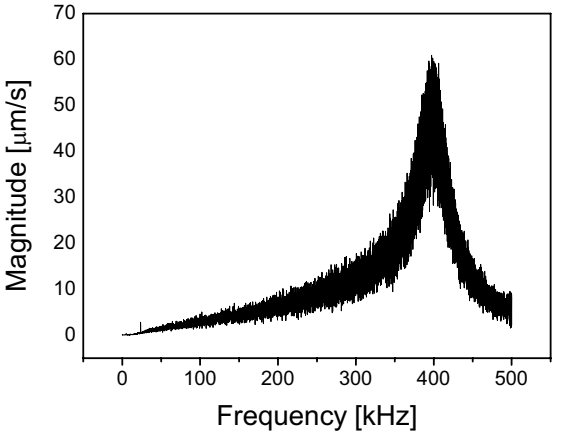

Fig. 7. Resonant frequency responses of micromirror with 16μm×16μm size

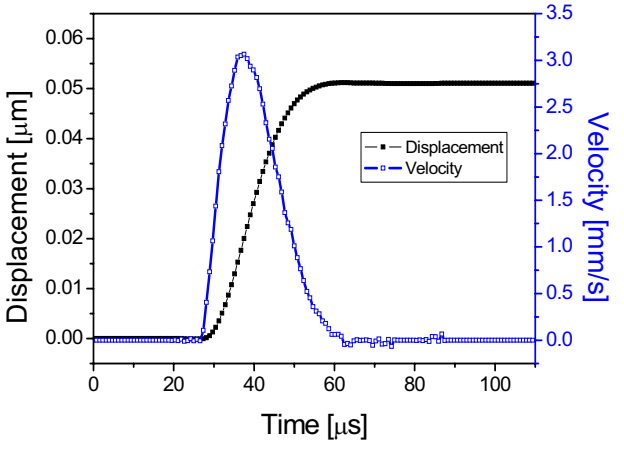

Fig. 8. Switching time responses of the fabricated 16μm×16μm micromirror to step function with 25V and 2 kHz

5. Conclusion

The seamless-picture projection display system with micromirror array and microlens array sheets has been proposed. Also, the 16μm×16μm micromirror using intedigitated cantilevers have been successfully developed to meet the requirement of the proposed seamless-picture projection display system. The fabricated micromirror which does not have any center hole in the mirror plate showed binary rotation angles of ±8.9˚at 85V. The resonant frequency was measured to ~400 kHz and the switching response time was ~15μs.

6. Acknowledgement

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7. References

1. L. J. Hornbeck, International Electron Devices Technical Digest, 1994, pp. 381-384
2. L. J. Hornbeck, Digest of IEEE/LEOS 1996 summer topical meetings, optical MEMS and their applications, pp.7-8
3. M. A. Mignardi, Solid State Technology, 1994, vol. 37, pp. 63-66.
4. J. I. Trisnadi, C. B. Carlisle, and R. M, Micromachining and microfabrication symposium, 2004, pp.5348-05.
5. L. Banks, M. Birch, D. Krueerke, SID 2006 digest, pp. 2018-2021.
6. J. M. Teijdo, F. Ludley, O. Ripoll, SID 2006 digest, pp. 2011-2014.
7. Huffman. J., Gong. C., IEEE proceeding of BCTM, 2005, pp. 163-168,
8. A. Huibers, P. W. Richards, R. Grasser, SID 2006 digest, pp. 1618-1621
9. S.-I. Chang, and J.-B. Yoon, The 15th international conference on solid-state sensors and actuators Tech. Dig. (Transducer' 05), vol. 2, pp. 1457-1460
10. S.-I. Chang, J.-B. Yoon, Dec., 2004, Optics express, vol. 12, no. 25, pp. 6366-6371.
11. J.-W. Jeon, B.-I. Kim, J.-H. Kim, H.-K. Lee, J.-B. Yoon, E. Yoon, and K. S. Lim, the IEEE Int. MEMS Conf. Tech. Dig., 2002, pp. 528~531.
12. J.-W. Jeon, D.-H. Kim, J.-B. Yoon, and K.-S. Lim, IEEE/LEOS international conference on optical MEMS and Their Application, Oulu, Finland. pp. 53-54